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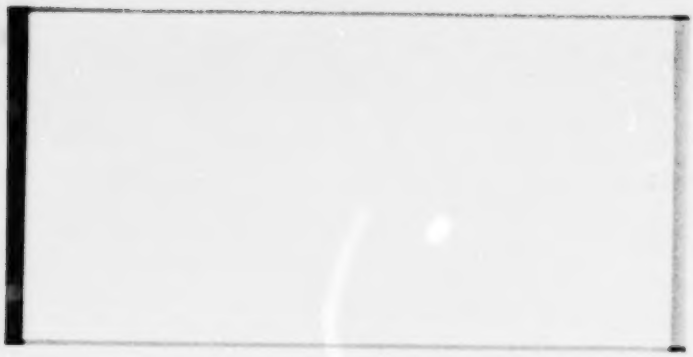

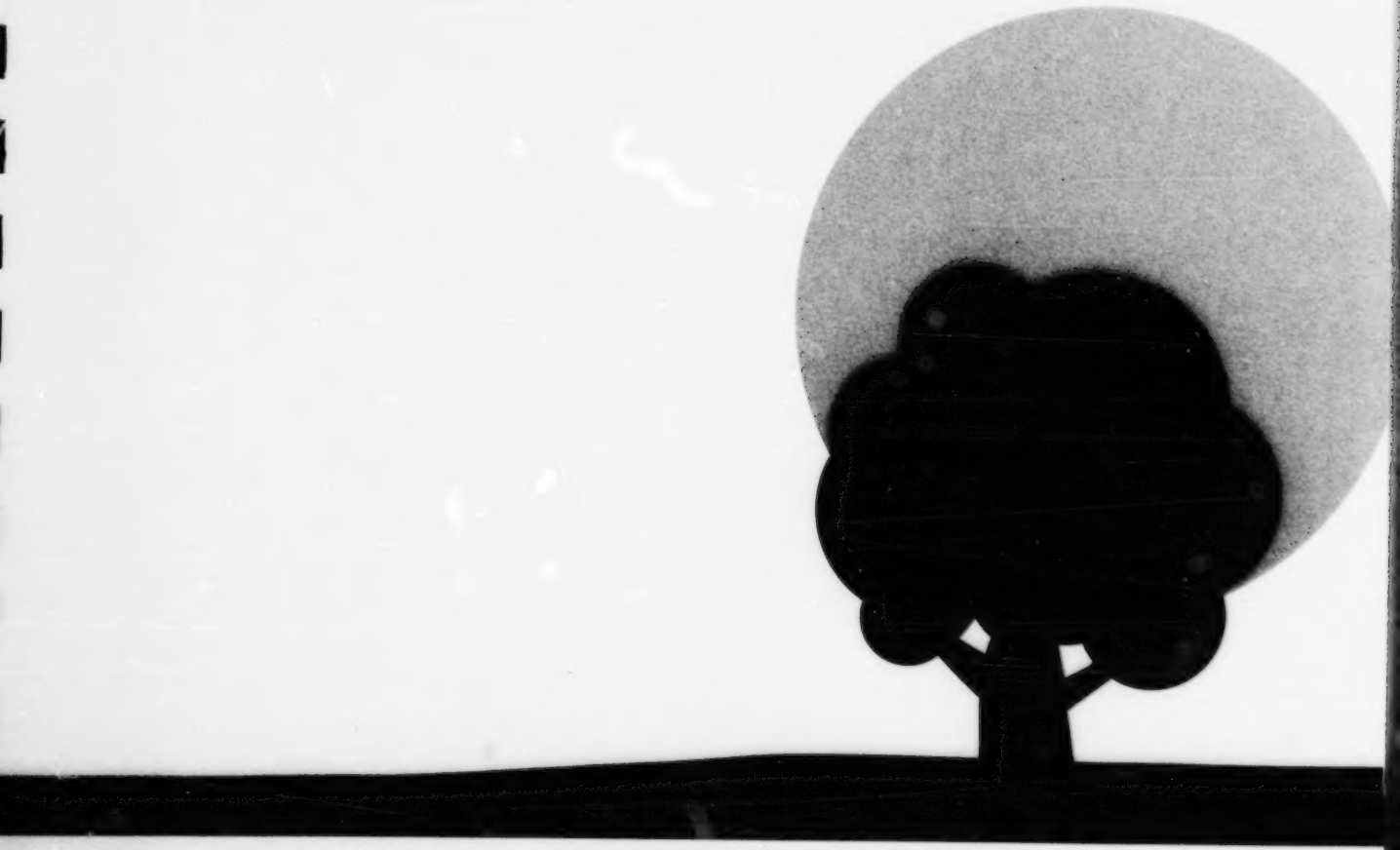

Canada

DATA ANALYSIS AND REPORT PREPARATION ON A BIOENERGY SELF-SUFFICIENT SYSTEM

BIOENERGY DIVISION

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PREFACE

A research, development and demonstration project (C-5) initiated in 1978 under the ENFOR program of the Canadian Forestry Service was not completed when the contractor, STOTT Timber Corporation of Sydney, N.S., was placed into receivership and ceased operation in 1982. Although some preliminary data had been collected, the main body of the project work was to be carried out after the integrated sawmill-residue/energy plant had achieved routine, stable operation of all components at full rated capacity.

Premature shutdown and dissolution of the mill terminated the ENFOR project with no compilation of data and no report on the project. In 1986, Ensyn was contracted to assemble whatever information could be acquired and prepare a wrap-up report on the project. The intent of this information report is to provide some insight into the apparent failure of an innovative concept that initially appeared to be a technically progressive step toward improved biomass utilization for energy self-sufficiency.

The information contained in this report was obtained from a variety of sources over a period of time roughly 5 years after termination of the mill operation upon which the original ENFOR project was based. Details are therefore often vague, being derived largely from the memory of individuals involved. Much of the test data collected was of a preliminary nature and could not be confirmed. However, the data has been utilized if cross-referencing with standard assumptions indicates that it is plausible.

While some economic information was obtained, the lack of complete cost data, the unusual economic conditions that prevailed, and the significant time lapse since the project termination preclude the development of any economic analyses of value.

Comments on mill operating problems and factors which contributed to closure of the mill were solicited mainly from sources connected with STOTT Timber and therefore reflect the contractors' views of the situation. No attempt was made to cover the views of other participants (customers, suppliers, government agencies, etc.) and therefore no judgments are intended.

ABSTRACT

A small hardwood sawmill complex was constructed in Sydney, N.S. to produce mine timbers from a local resource of unutilized maple and birch logs. A total mill residue utilization concept was included in the plant design. Hog fuel was burned in twin packaged boilers to provide steam to a IMW turbogenerator for mill electrical energy. Sawdust and pulverized solid trim were dried in a wood-fired flash dryer and densified in a dual-line ram press system that produced fuel-logs for the home heating market.

Although financial difficulties forced closure of the mill before full capacity operation of the fully integrated complex had been achieved, the project had demonstrated that small-scale energy self-sufficiency and total residue utilization were not technically limited. The constraints on implementation were largely economic with financial viability dictated by utilization factors.

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EXECUTIVE SUMMARY

A research, development and demonstration project initiated in 1978 under the ENFOR program was not completed when the contractor, STOTT Timber Corporation, was placed into receivership and ceased operation in 1982. Very little technical data had been compiled and no report prepared. ENSYN was contracted to assemble any information available on the project in order to provide some insight into the apparent failure of an innovative concept that appeared to be a progressive step toward improved biomass utilization for energy self-sufficiency.

Crown lands in Cape Breton, N.S. had significant hardwood stands that were not being utilized. This resource was considered adequate to support a short-log sawmill, cutting about 12,000 m3 per year of birch and maple to supply mine timbers to the Cape Breton coal industry. Faced with high costs for grid electricity and residue disposal, it was decided to include a residue-fueled boiler system to supply steam to a turbine-generator for self-generation of the mill's electrical demand. Since there was no local market for hardwood chips, a densification system was included to convert the dried, pulverized sawdust and chips into packaged fireplace logs.

The objectives of the ENFOR project were to support the demonstration of total residue utilization for mill energy generation and production of an energy-dense solid biomass fuel, and to acquire technical and economic data on the startup and operation of the integrated complex.

Although full-capacity, routine operation of the full integrated complex had not been achieved, the major systems had been proven operational. The sawmill had achieved rated capacity on a 1-shift basis for short periods but was hampered by an inadequate log debarking system and difficulties with pneumatic transport of mill residues. The boiler-turbine system was fully operational and able to operate the mill on self-generated power although the capacity was barely adequate for the average load and difficulties occured as a result of load surges. The fuel-log densification system had been operated at rated capacity providing a high quality product. Unfortunately, performance of the residue-fueled suspension burner providing the thermal energy for the fuel-log furnish dryer was unsatisfactory. The maximum burner output was barely sufficient for the drying load required and was apparently designed for a much finer fuel than the fuel-log furnish being utilized. As a result, the residence time was insufficient to allow fuel burnout and sparklers escaped from the burner causing fires in the dryer and dry fuel storage areas.

Although a number of technical difficulties had been encountered, the brief operation of the STOTT plant demonstrated that energy self-sufficiency and total residue utilization are not technically limited. Small-scale commercial systems are available that, when properly implemented, will meet performance specifications and provide marketable products. The constraints are largely economic with financial viability dictated by general economic conditions and utilization factors.

RÉSUMÉ

Un projet de recherche, de développement et de démonstration, amorcé en 1978 dans le cadre du programme ENFOR, n'était pas terminé lorsque l'entrepreneur, STOTT Timber Corporation, a fait faillite et cessé ses activités, en 1982. Très peu de données techniques avaient été compilées, et aucun rapport n'avait été rédigé. On a fait appel à la société d'ingénierie ENSYM pour rassembler des renseignements sur le projet, afin d'expliquer cet échec d'une application innovatrice favorisant l'utilisation de la biomasse pour atteindre l'autosuffisance énergétique.

À Cape Breton, en Nouvelle-Écosse, d'importants peuplements de feuillus, situés sur des terres publiques n'étaient pas exploités. Il a donc été décidé d'aménager une scierie à billons, qui couperait 12 000 m^3 par année de bouleau et d'érable, afin d'approvisionner l'industrie du charbon de Cape Breton en bois de mine. Étant donné les coûts élevés des réseaux de distribution électrique et de l'élimination des résidus de bois, on a prévu une chaudière alimentée aux résidus pour approvisionner en vapeur un turbo-réacteur qui permettrait à l'usine de produire sa propre électricité. Comme il n'existait pas de marché local pour les copeaux de bois dur, une installation de densification, destinée à convertir la sciure et les copeaux pulvérisés en bûches, a été aménagée.

Le projet ENFOR avait les objectifs suivants : contribuer à démontrer l'utilisation complète des résidus, afin de produire l'énergie nécessaire au fonctionnement de la scierie et de fabriquer des biocombustibles solides à haute densité énergétique, ainsi que d'acquérir des données techniques et économiques relatives à la mise en oeuvre et à l'exploitation d'un complexe intégré.

Même si l'exploitation régulière et à pleine capacité du complexe intégré n'a jamais été réalisée, les principaux éléments se sont avérés fonctionnels. La scierie a atteint sa puissance nominale en étant en service pendant un quart de travail sur de courtes périodes, mais un système d'écorçage inadéquat et les difficultés survenues dans le système de transport à air comprimé des résidus ont entravé son fonctionnement. Le système de turbine à vapeur a fonctionné à plein rendement, mais sa puissance suffisait à peine à la charge moyenne d'électricité de la scierie, et des difficultés se sont présentées en périodes de pointe.

L'installation de densification des bûchettes combustibles a fonctionné à puissance nominale et donné un produit de qualité. Malheureusement, le rendement du brûleur en suspension alimenté aux résidus, qui fournissait l'énergie thermique au séchoir alimenté aux bûchettes combustibles, n'était pas satisfaisant. À puissance maximale, le brûleur suffisait à peine aux besoins en séchage et semblait conçu pour un combustible beaucoup plus raffiné que les bûchettes utilisées. Le temps de séjour n'était pas suffisant pour permettre à celles-ci de brûler entièrement et des étincelles provenant du brûleur ont provoqué des feux dans le séchoir et les réservoirs de stockage du combustible sec.

En dépit de certaines difficultés techniques, la brève exploitation de l'usine STOTT a montré que l'autosuffisance énergétique et l'utilisation de l'ensemble des résidus ne sont pas limités sur le plan technique. Certains systèmes commerciaux à petite échelle, mis en service convenablement, satisferont aux caractéristiques de rendement et permettront d'obtenir des produits pouvant être mis en marché. Les contraintes sont principalement financières et la rentabilité repose sur la conjoncture économique et les facteurs d'utilisation.

1.0 INTRODUCTION

In the late 1970s, rapidly rising petroleum prices and concern over the possibility of liquid fuel shortages led to an increased interest in the options for generating thermal and electrical energy from Canada's abundant biomass resources. An area with considerable short-term promise was the forest products industry (particularly sawmills), where a significant portion of the log input was not utilized as primary product and was often available as fuel for use in combustion systems.

Although many small mills traditionally burned their residues to provide energy for lumber drying and mill heating, and a few very large mills were producing electricity from wood fueled high-pressure steam turbine-generators, there were very few small-scale generating systems operating in Canada on biomass fuels. The concept of a small-scale wood-residue fueled electrical generating system was therefore of interest to the federal government and within their mandate to support the demonstration and development of bioenergy technologies. STOTT Timber Corporation of Sydney, N.S. was considering construction of a small-scale integrated mill complex featuring a hardwood sawmill, wood-residue fueled combustion system and electrical generating package, and a wood chip based fuel-log production plant. In March 1978, the Cape Breton Development Corporation (DEVCO) contacted the Eastern Forest Products Laboratory seeking federal funding in support of the energy system through the Canadian Foresty Service (CFS) program for "Energy Demonstration Plants for the Wood Products Industry". A proposal was submitted to the CFS committee in April and received a generally favourable response dependent on clarification of the technical suitability of the bioenergy system. After several months of negotiations, the project was approved in October 1978 for support under the CFS ENFOR program which had just been inaugurated. Participation included the private sector, the Provincial Government (DEVCO and N.S. Lands and Forests) and the Federal Government (DREE and ENFOR).

2.0 OBJECTIVES

The ENFOR project (C-5) statement of work listed the overall objective as:

> "To provide a technical and economic assessment of energy self-sufficiency in a small hardwood sawmill, achieved through total residue utilization by conversion to thermal and electrical energy, and production of a marketable densified biomass fuel".

Specific objectives were:

- to demonstrate the total utilization of residues from a small sawmill for the production of energy by on-site combustion to generate total mill electrical and thermal requirements plus conversion of remaining residues to a marketable, energy-dense biomass fuel

- to acquire specific, detailed, technical information on the fibre and energy balances of all aspects of an integrated sawmill/fuel-log plant

- to obtain complete costing and operating data on the construction, startup, testing and operation of a small scale steam-cycle electrical generating system

- to obtain technical and economic evaluation of the production and marketing of a residue-based, densified fuel

- to create a model of small scale residue-energy systems for use in sensitivity analyses and as the basis for feasibility studies of similar mill systems in eastern Canada.

The study approach involved an undertaking by the contractor (STOTT Timber Corporation) to:

- engage a qualified individual to obtain, compile, evaluate and assess data on the installation and operation of the integrated plant and prepare a report;

- work would cover startup and initial operation in general plus detailed technical data acquired over a significant operating period after the integrated plant had achieved steady state operation at full capacity.

Details of the information to be gathered are provided in Appendix I.

3.0 BACKGROUND

Crown lands in Nova Scotia had significant areas of hardwoods which were not being utilized by the pulp industry who held the timber cutting rights. For hardwood stands, which represented 29% of the timber resource, less than one-third of the allowable cut was being harvested. In addition, non-utilization of the deciduous species inhibited full utilization of softwoods where they occured in mixed stands.

In 1976 the demand for mine timbers in Cape Breton was approximately 8,000 m3 (3.5 million board feet) per year, based on a coal production of less than 2 million tonnes per year. It was anticipated that coal output would increase to 3.5 million tonnes per year in the period 1979-2000, creating demand for an additional 7,000 m3 (3 million board feet) per year of timbers. Since the majority of the timbers being used were imported from New Brunswick, there was pressure to improve the local economy by supplying this demand from an indigenous Island resource.

A special Federal-Provincial task force had been formed to study the problem with the objectives of:

- creating permanent employment by more fully utilizing the available hardwoods,
- increasing the short-run availability of softwoods,
- developing the necessary information to undertake more effective management of the hardwood resource.

With the encouragement of this task force, the Cape Breton Development Corporation (Industrial Development Division) undertook to set up a joint venture with the private sector (STOTT Aluminum Corp. Ltd.) to establish a sawmill to produce mine timbers from low-grade hardwoods to be obtained from a 6000 ha tract on Cape Breton.

Logs from the predominantly birch and maple stands were expected to be high-line F-3 or low-line F-2, not adequate for a long-log mill producing factor lumber. The logs were considered suitable for a short-log operation producing principally mine packs, if the inclusion of rot was restricted and sweep or crook in small diameter logs was kept to a minumum. Accordingly, the concept was developed for a Sydney-based 12,000 m3 (5 million board feet) per year sawmill to be operated on a single-shift for supply of mine timbers to the Coal Division of DEVCO.

At the time, there was no local market for the bark, sawdust, chips or other residues to be generated by the mill. This would pose a major disposal problem, with an estimated annual cost of about $50,000 for incineration or landfill. Also, preliminary estimates of the costs for grid electrical power for the mill were $145,000 per year.

To address these problems, it was decided to include a residue-fueled boiler system to supply medium-pressure steam to a turbine-generator for production of the electrical power required by the mill. Clean residues (chips, sawdust) would be utilized as furnish for production of densified fuel-logs.

4.0 PROJECT HISTORY

The basic concept for a hardwood utilization complex had been formulated over the period from 1972-76, with negotiations carried on during 1976-79. In February of 1979, project approval was secured and construction begun in July at the 16 hectare Grand Lake site. By year's end, the building was complete, the installation of sawmill equipment had begun and the harvesting operations were underway.

Equipment installation continued in 1980, with the sawmill completed and fully operational by September and the boilers and electrical generating system tested in December. Late delivery of the presses from overseas delayed startup of the fuel-log plant until July 1981.

By the end of 1981, full operation on self-generated power had been achieved for the integrated plant on a one-shift basis. Unfortunately, financial difficulties forced the Corporation into receivership in April 1982 and operation was terminated.
Unsuccessful attempts were made to secure a buyer for the complete mill and ensure continued operation. In 1984, a liquidation sale was held for disposal of all mill assets.

5.0 SYSTEM DESCRIPTIONS

5.1 Sawmill Operations

5.1.1 Woodlands

Although STOTT Timber would have preferred to purchase the raw material from an independent source, (for example, a pulp company woodlands department or private logging contractor), it was necessary to set up a company-controlled (but fiscally independent) woodlands operation to guarantee security of log supply. Harvesting operations (including road building) were carried out on Crown lands under lease to a major N.S. forest industry company. Although the softwoods had been harvested, the pulp company had no use (at that time) for the hardwood stands which had been left untouched and were generally mature or overmature.

The raw material input to the sawmill consisted of 31,300 m3 (13,000 cords) per year of hardwoods with a species distribution of roughly 25% each for hard maple, soft maple, yellow birch, and white birch, plus the occasional log of ash or beech. Stands were selectively cut based on a minimum log dimension of 20 cm top diameter and 2.5 m length and a maximum log length of 7.6 m. To avoid re-processing at the sawmill, all bucking was done at roadside to produce nominal log lengths mainly of 2.4, 3.0, 3.7 and 4.3 m. The typical log was 3 m in length with a top end diameter of about 25 cm.

Provincial forestry data had predicted a yield of 87 m3/ha but the actual yield of material suitable for chuck block production was much lower, in many cases only 31 m3/ha.

The woods operation employed a foreman plus a labour force of 14, and combined manual felling with mechanized removal utilizing 3 cable skidders and 2 knuckleboom loaders. Logs were moved to the mill by 3 tractor-trailers over a typical haul distance of 56 km. Loads ranged from 21 to 30 tonnes (green weight) with an average of about 23 tonnes.

At the mill, incoming loads were weighed on a 60 tonne capacity truck scale which was controlled from within the mill office. Initially, every fifth load, and later every tenth load, was check scaled according to the N.B. Log Scale. The weight scale then formed the basis for payment of stumpage (a single rate for all hardwood species).

5.1.2 Primary Breakdown

Logs received at the mill were dry decked without sorting by species or size. Bark loss was generally low and tests indicated an average log MC of 39.5%, with a range of roughly 33-44%. A log pond was not utilized so bark MC was not excessive. Movement of logs in the yard, and their delivery to the mill infeed deck were handled by wheeled loaders.

Conveyed laterally into the mill on a chain live deck, logs were passed to a rosser head debarker with 56 kw cutterhead drive. Debarked logs were transferred to either the headrig line or the Scrag line. Generally, logs less than 25 cm in diameter and short logs went to the Scrag saw, while large logs and high quality logs went to the headsaw.

The Scrag system featured twin 1.2 m diameter saws each powered by a 56 kw motor. Four log turners and a centering system were utilized with the hydraulic feed overhead dogging carriage. The automatic setworks could accomodate logs from 15 to 41 cm in diameter and 1.8 to 4.9 m in length.

The headsaw featured a 1.3 m main saw with 112 kw drive and a 0.9 m top saw with 22 kw drive. A 4-block automatic carriage had hydraulic/electric setworks with pushbutton controls and was operated by a hydraulic shotgun feedworks.

The primary breakdown basically slabbed the logs on 2 sides to produce 15 cm thick cants which were transferred to the combination edger for secondary breakdown.

5.1.3 Secondary Breakdown

Cants from the Scrag and headsaw and all side boards were transferred to the combination edger for secondary breakdown. This 185 kw unit featured split top feedrolls, automatic board-side setworks and carbide tipped saws.
Chuck blocks were trimmed to length by a 0.8 m cut-off saw fitted with front and rear clamps, and exited the mill on a belt conveyor to palletization and shipping. Boards passed from the edger to a 9 saw overhead drop trimmer, then were transferred to a 4-bay chain drive drop sorter.

5.1.4 Products and Marketing

The main output from the sawmill was chuck blocks (mine timbers) which were supplied to the Coal Division of DEVCO under a 15 year contract covering a minimum of 7000 m3 (3 million board feet) per year.

Specifications included:

- maple or birch (small percentage of beech allowed)
- blocks must have a boxed heart
- less than 10% wane allowed on one edge
- blocks must be sound with no heart checks; sound knots allowed
- delivered green, on pallets.

Sizes for the blocks were 15.2 cm square in lengths of 61 cm, 76 cm or 152 cm. Output was approximately 10 %, 20 % and 70 % for the three lengths respectively. The blocks were solid piled on 1.5 by 1.2 m pallets and secured with metal strapping. Each pallet held 2.3 m3 and weighed roughly 2 tonnes. They were delivered the same day to the mine site, a distance of about 26 km.

The secondary sawmill product, roughly 40% of the total, was factory lumber. Roughly 90% of the lumber was 2.5 cm in thickness, of various widths and in lengths from 1.5 m to 4.9 m in 0.3 m increments. The remaining material was 5 cm in thickness with lengths from 2.4 to 3.7 m. Rough green dimensions were plus 0.3 cm in thickness, plus 0.6 cm in width and plus 2.5 cm in length.

The lumber was sorted by length and width then stacked on 2.5 cm square stickers for air-drying. Pile foundations were made from chuck blocks and roofs were not used. Roughly 30-45 days were required to reduce the MC from 38% to 18-19%. When dry, the lumber was repiled in solid bundles of 4.9 x 1.2 x 1.2 m and strapped for shipment. A private trucking company was contracted to deliver the bundles to St. John, N.B. for loading on deck and shipping to the U.K.

The lumber was sold on a mixed grade and mixed species basis subject to the grade being not less than No.3 Common (NHLA grades) with not over 25% No.3C in a shipment. Actual grade yields were roughly 12% FAS and Select, 25% No.1C, 38% No.2C, and 25% No.3C. The price received was that for No.2C lumber.

5.1.5 Residue Handling

Debarker residue was conveyed to a 75 kw bottom discharge bark hog, then was pneumatically delivered to the bark cyclone on top of the fuel silo by a 45 kw bark blower system.

Solid trim was collected from the primary and secondary breakdown saws and passed to a 43 m vibrating conveyor for delivery to the chipper. This conveyor included a sawdust screen section and a fiberglass section fitted with a metal detector system. The 120 kw 1.5 m, 6-knife chipper was coupled with a vibrating chip screen with 1.9 cm openings which returned oversize material for re-chipping. A 45 kw chip blower transferred the sized chips to a cyclone on the fuel-log feedstock silo.

Sawdust was collected and delivered to the chip line by a 45 kw blower system. The flow of chips/sawdust could be diverted to the fuel silo when required

5.2 Energy System

5.2.1 Fuel Storage and Delivery

Debarker residue, sawdust and chips were stored in the fuel silo. Of concrete slab construction, the 4.9 x 12.2 m silo was located adjacent to the boiler room on a poured concrete base. It was fitted with a concrete slab top on which were mounted the 2.1 x 3.0 m chip/sawdust cyclone and the 1.2 x 2.1 m bark cyclone.

Twin screws in a trough at the bottom of the silo unloaded fuel to a 7.6 m single screw conveyor for transfer to the fuel metering bin located within the boiler room. The 6 tonne capacity rectangular steel metering bin was fitted with twin feed screws (one per boiler, independently controlled) driven by 1.1 kw variable speed D.C. motors. Fuel passed from the metering screw to a 22 kw constant speed blower for pneumatic delivery through a 10 cm diameter pipe to the top of each boiler. This transport air, at a velocity of about 25 m per s, was part of the secondary air supply to the boilers.

5.2.2 Boilers

Two model 425S MOTTPAC boilers (GWB VEKOS basic design) were installed in the boiler room (with space reserved for the future addition of a third boiler). Each unit was factory-assembled on a structural steel base with a dry weight of approximately 25 tonnes, an overall length of 7.9 m, width of 3.6 m and height of 3.5 m. Exhaust gases were vented through the roof by a 0.7 m diameter by 9.1 m high steel stack mounted directly on each boiler.

The boilers were of electrically welded steel of the Scotch Marine design with 3-pass horizontal firetubes. The combustion chamber was fitted with an air-cooled cast iron static grate. Fuel delivered pneumatically to the top of the boiler passed through a drop-tube into the combustion chamber. A static diffuser combined secondary air with the fuel delivery air to spread the fuel in a swirl pattern. Fines were burned in suspension while the larger material completed combustion on the grate.

The cyclonic action of a rear-mounted multiple-cell grit arrestor trapped large particulate which was pnuematically transported back to the combustion chamber for re-firing.

Combustion air was supplied by a 22 kw forced-draft fan at 33 cm water column pressure. Boiler control was automatic with modulating control of fuel delivery rate and primary and secondary combustion air.

The 425S model boilers were equipped with a bank of superheater tubes which enabled the boiler output to be specified as 6351 kg/h (14,000 lb/h) of steam at 1.59 MPa (230 psig) and 310 C (590 F).

5.2.3 Feedwater System

Make-up water was pumped from a 79 m deep well to a 6800 l pressure tank. Condensate was returned from the building heating and hot water systems. A zeolite and ion exchange water treatment system was required for the relatively hard make-up water.

The feedwater system for each boiler consisted of an elevated 6400 l storage tank which utilized low-pressure exhaust steam to maintain a feedwater temperature of 88 C, plus duplicate 19 kw electrical feedwater pumps.

5.2.4 Turbine-Generator

The superheated steam from the boilers was delivered through insulated pipe to the Westinghouse model CE 125 L steam turbine. Fitted with a Woodward VG-8 governor, the turbine was rated at 1000 kw at 6000 rpm on steam at 1.55 MPa (225 psig) and 313 C (595 F) when exhausting at 34 KPa (5 psig). The steam rate was specified as 12.5 kg/kw/h (27.49 lb/kw/h) at rated output.

The turbine output shaft speed was reduced by a Lufkin model N1200C single reduction, parallel shaft, double helical speed reducer unit. This was direct coupled to a Brown-Boveri 1250 kVA, 0.8 PF, 3 phase, 60 Hz, 550 V, 1800 rpm, 4-wire high speed synchronous generator.

A small portion of the exhaust steam was used for building heating, water heating and feedwater heating, but the majority was vented to atmosphere through a dump stack. A Westinghouse electrical distribution panel was complete with interlocks for turbine-generator, diesel-generator or grid power usage.

5.2.5 Diesel-Generator

Startup and standby power were provided by a skid-mounted Caterpillar model T3412 375 kw diesel engine-generator set fueled from a 4500 l oil storage tank.

5.3 Fuel-Log System

5.3.1 Preparation and Delivery of Furnish

Raw furnish for the fuel-log plant (chipped solid trim and sawdust) was pneumatically conveyed to a cyclone mounted on the top of a 40 t capacity concrete slab silo located adjacent to the boiler-fuel storage silo. The silo unloader system and a single-screw transfer conveyor delivered the raw furnish to a 3.6 m3 overhead, live-bottom, metering bin which fed an SPM double rotor hammermill.

To avoid high noise levels in the plant, the size reduction equipment was located in a separate enclosure adjacent to the main plant. The SPM type 1000/1050 hammermill featured two 1.1 x 1.0 m rotors, each belt-driven by a 112 kw electric motor. Although various screen sizes were tried, best results were obtained with the 1.3 cm screens.

After size reduction, the MC of the furnish was reduced to 6 1/2 - 7 1/2% in an SPM designed, 15 m high flash dryer that had been constructed locally. Wet furnish was conveyed pneumatically from the hammermill to the dryer and introduced via rotary valve. The inlet temperature of the dryer was about 340 - 400 C and the exhaust temperature was about 180 - 195 C. Dry furnish was separated from the exhaust gases in a 2.3 m diameter by 6 m high cyclone and delivered to a metering bin with variable speed discharge screws that fed to the pre-press system on the fuel-log presses.

Thermal energy for the furnish drying was supplied by a refractory lined, cyclonic flow suspension burner operated on dry, fuel-log furnish. Designed by RASKINS of Montreal, the burner was rated at 10.5 GJ/h (590 kg/h of fuel) and provided a furnace outlet temperature of about 370 - 425 C. Dry fuel was pneumatically conveyed from the press-line main metering bin to a cyclone at the burner, and dropped through a manually adjusted flow control valve. Combustion air-flow was automatically altered as the fuel flow was adjusted. A 10 to 20 minute oil-fired preheat period was required for burner startup.

5.3.2 Densification Presses

The densified wood fuel-logs were produced by two parallel press lines, each comprised of a ram type press, cooling line, log cutoff and return system, and packaging station.

The SPM model 89/200 single head presses each weighed about 6 t, developed piston head pressures in the order of 1200 kg/cm2 and had a rated capacity of 1.1 to 1.5 t/h. They featured full independent control consoles, automatic pressurized-oil lubrication, and hydraulic die pressure control.

Feed material was metered from the overhead surge bin by a variable speed screw to the auger type pre-press section of the press. This packed the wood particles into the main press chamber where the reciprocating ram forced the dry, sized furnish through a tapered,

circular die, generating sufficient heat and pressure to form a *self-bonded, continuous, solid log output.*

The press dies were fitted with a water jacket and circulation system for die temperature control. For about 10 minutes prior to startup, hot water from a small electric boiler was used to preheat the die while the water circulation could be used for die cooling as required during steady-state operation. For overnight shutdown, a quantity of oil-soaked sawdust was fed into the press which maintained the plug backpressure required for rapid re-start, but without the risk of plug seizure.

5.3.3 Cooling and Packaging

The compressed wood cylinder exiting the press die was at a relatively high temperature and required extensive air-cooling prior to handling. A steel support structure was used to hold the extrusion in a straight line as it moved along the 36 m cooling line. A compressed-air activated cutoff device broke the continuous extrusion into individual pre-set log lengths which moved down a transfer chute onto a return belt conveyor. A cross-conveyor section passed the logs to an accumulator table, then to a manually operated plastic wrap station and a heat-shrink tunnel.

5.3.4 Products and Marketing

Output from the fuel-log plant consisted of compressed wood fireplace/stove logs with no binders or chemical additives. Each log was about 90 mm in diameter and about 300 mm in length. Tests performed on a single log sample (Appendix II) showed an average specific gravity of 1.1, an ash content of 0.47% and a higher heating value of 19.3 MJ/kg. When ignited, a single log was reported to burn from a half to about one hour, depending on the air draft. Each log weighed about 2.2 kg and had a MC normally less than 7%.

This prepared solid fuel was marketed in three-log flat packages (about 7 kg) shrink wrapped in clear plastic with colourful paper inserts to identify the product and provide instructions for safe use. Wholesale shipments were made via 144-package pallet loads, stretch wrapped in clear plastic.

Fuel-logs had been sold in local supermarkets and service stations, test shipments had been trucked to Toronto, and the U.S. market had been investigated, but the major market was to have been overseas. Container shipments had been made on a trial basis with an excellent reception in Europe. The clean burning logs qualified as a smokeless fuel for European cities where air pollution restrictions on coal and peat burning were in effect. Markets had been secured for total fuel-log production, particularly in the Netherlands and England. It was planned to ship 2-3 times per year from Sydney in 2500 tonne lots loaded on small ocean freighters. Fuel-logs were sold for $1.25 per package (about $180/t) f.o.b. the plant with retail prices to the consumer of up to $2.75 per package.

6.0 MATERIAL AND ENERGY BALANCES

6.1 Sawmill

6.1.1 Sawmill Production Capacity

The design output specified for the sawmill complex was 11,800 m3/y (5,000,000 bd.ft./yr). The mill was operated on a one-shift basis, 7.5 hours per day (8:00 to 16:30 with a 30 minute lunch break and two 15 minute rest periods). With a five-day week and mill shutdowns of three weeks in summer and one week at Christmas, plus statutory holidays, the yearly operating time would have been 1762.5 hours. To achieve the specified yearly production, the required mill throughput would have been 6.7 m3/h. The target set by mill management was 7.1 m3/h.

Short term tests conducted early in the mill's operation indicated an average production rate of 4.6 m3/h or only about 69% of the required capacity. However, several tests did achieve a production rate at, or very near the design capacity. Prior to cessation of mill operations, an average production rate of 5.9 m3/h was reported to have been reliably achieved.

6.1.2 Lumber Yield

Several pallets of chuck blocks had been weighed to establish a ratio of green weight to scale volume. One pallet contained 960 board feet of blocks or 2.265 m3 plus 29 board feet of lumber in the pallet base or 0.080 m3.

Table 1. Lumber Weight/Volume Ratio

Pallet Number	Weight (kg)	Volume (m3)	Ratio (kg/m3)
1	2,400	2.345	
2	2,440	2.345	
3	2,398	2.345	
4	2,366	2.345	
5	2,410	2.345	
TOTAL	12,014	11.725	1025

Several tests had also been carried out to determine the wood moisture content.

Table 2. Wood Moisture Content

Sample Number	Moisture Content - Wet Basis (percent)
1	40.8
2	41.4
3	44.4
4	40.4
5	40.3
6	44.4
7	37.5
8	37.5
9	42.5
10	38.3
11	35.1
12	32.9
	Average: 39.6
	Range: 32.9 - 44.4

The range of 32.9 to 44.4 and average of 39.6 percent agree well with published values for the MC of maple and birch (Appendix III, Table 1).

Combining the average MC (39.6%) with the green lumber weight/volume ratio yields a value for wood specific gravity of 0.619. This value is within the upper level of data for hard maple but significantly greater than the value of 0.53 derived from averaging published data for an even mix of the four species being processed by the mill (Appendix III, Table 2). Since a MC of 48 percent would be required to yield the test data based on an average S.G. of 0.53, it has been assumed that the pallet loads measured were composed primarily of hard maple.

For use in calculating lumber weight an average S.G. of 0.55 has been assumed and a MC of 40% utilized. These give a lumber weight to volume ratio of 917 kg/m3 green or 550 kg/m3 dry basis.

Log input and lumber output were recorded for a series of nine test periods and are shown in Table 3. The total output of blocks was recorded as 24,626 board feet. Since blocks are cut to full dimensions, this is equivalent to 58.11 m3. The total lumber output was recorded as 15,120 board feet. Using a correction for lumber oversizes of 3.2 mm for thickness and 6.4 mm for width on the 90% 25.4 mm by 152.4 mm material gives a lumber volume of 41.57 m3.

Table 3. Lumber Yields

Test No.	Scale (FBM)		Green Wt. (kg)	Boards (FBM)		Blocks (FBM)		
	Total	Cull		Export	Commercial	6x6x2.5	6x6x2	4x4x4
1	4342	919	21,200	597	710	2273	24	11
3	4672	2147	26,200	474	778	1868	174	101
4	5750	2211	29,800	670	704	2400	306	96
5	5153	465	26,900	863	784	2160	888	-
6	4002	479	20,700	696	450	1365	96	-
7,8,9	14,170	3481	76,690	1901	2055	5445	588	101
10	4332	2064	23,550	591	786	1658	276	64
11	5080	2250	28,400	843	614	2236	282	-
16	4330	479	23,600	858	746	1740	474	-
TOTAL	51,831	14,495	277,040	7493	7627	21,145	3108	373

Total sawn timber output was 99.68 m3 or 98,040 kg (based on a S.G. of 0.55 and MC of 40%). This represents a yield of 35.4% when compared to the total green weight of log input, 277,040 kg. This yield, which seems low for a mill cutting 60% blocks, was obviously influenced by the low quality of the logs (28% cull as scaled) and the inexperience of the mill staff. It was estimated by mill management that a yield of 45% had been achieved after longer operation.

6.1.3 Residue Production

Total log input can be subdivided into three components; water, dry wood and dry bark. This requires data on wood MC, bark MC and bark:wood ratio. No data were taken at the mill to show bark MC but a measurement was apparently made to relate green weight of a bark sample to the volume. This data showed a green density of 900 kg per m3. If a typical value for bark basic specific gravity is taken from the literature (0.61) then the average bark moisture content would be 32%. This shows good agreement with data from other mill studies on hard maple which indicated a slightly lower bark than wood MC.

Data taken at the STOTT operation do not directly indicate the bark:wood ratio, but measurements were apparently taken of bark thickness. An average of 11.1 mm was obtained. This value, when combined with an assumed bark density and wood density, can provide a bark:wood ratio if an average log size is selected. Based on an indicated average log length of 3.05 m and data on bark area for a sample of logs from 7 mill tests, it is possible to calculate an average log diameter for the sample of 42 cm.

Using these values (bark thickness of 11.1 mm, log diameter of 42 cm, bark S.G. of 0.61 and wood S.G. of 0.55) gives a bark yield, dry weight basis, of 10.5%. This is consistent with a bark yield of 9.8% (for 98% bark coverage) found by Forintek in mill studies on hard maple and with CPPA studies which showed 11.2 and 12.0% for maple and birch of much smaller diameters. If it is assumed the logs at the STOTT mill had 95% bark coverage, a bark yield of 10% can be selected for use in mass balance calculations.

Using the data and assumptions derived to this point, allows the following inputs to be established (based on a production rate of 5.9 m3/h):

Material Input:

	kg/h	t/d
Dry Wood	7389	55.4
Dry Bark	821	6.2
Water	5311	39.8
TOTAL	13,521	101.4

Sawmill outputs consist of the solid timber products, debarker residues, sawdust and the chipped solid trim. Since no mill fiber audits were carried out to measure the outputs of sawdust, chips or debarker residues, they must be determined by calculation based on estimates and balances.

The debarker residue consists of bark plus wood removed from the log surface with the bark. Mill personnel indicated that debarking was relatively complete with an estimate of about 1% bark left on the logs. Therefore the dry bark component output would be 813 kg/h. The amount of wood loss is difficult to estimate but with a rosser head debarker it is relatively high, particularly if the bark left on the logs is kept to a minimum.

Tests by Forintek showed debarker residue wood content (dry weight basis) of about 45% for hard maple and 35% for oak, which were equivalent to 10% and 6% of the total log dry basis input weights. Although mill personnel indicated that wood loss was low, it does not seem reasonable to expect less than 5% wood loss. This would be equivalent to 410 kg/h for a total debarker residue production of 1223 kg/h dry weight basis.

Although a very rough estimate of sawdust could be made, there is no point served in attempting to separate sawdust output from chip production since both streams were combined in the transfer to the fuel-log furnish storage silo (or fuel silo, if required).

Therefore, with the assumption of a 1% physical loss (falling from conveyors, dusting etc.) a material output for the sawmill can be listed as:

Material Output:

	Debarker Residue		Fuel-Log Furnish		Lumber	
	kg/h	t/d	kg/h	t/d	kg/h	t/d
Dry Wood	403	3.0	3667	27.5	3245	24.3
Dry Bark	805	6.0	8	0.1	-	-
Water	645	4.8	2450	18.4	2163	16.2
TOTAL	1853	13.9	6125	45.9	5408	40.6

Thus for the sawmill operation, distribution of the total log input (dry weight basis) could be estimated as; 39.5% to primary (lumber) product, 14.7% to boiler-fuel use, and 44.8% available as secondary (fuel-log furnish) product.

6.1.4 Energy Requirement

Little specific information on the energy requirements of the sawmill operation could be obtained. Although the mill had been operated on grid power, and a load meter was included in the electrical control panel, no data had been collected on electrical demand. The nameplate rating for all electric motors in the sawmill had been listed, which showed a total connected load of 985 kw. Information on lighting or other non-motor demands was not included.

If it is assumed that peak demand would be about 65% of total connected load, and average demand about 50%, with a 3% requirement for lighting and incidental requirements, then the sawmill electrical requirement would have been 655 kw peak and 507 kw average.
Thermal requirements of the sawmill were for building heating only (no hot ponds or kilns) and were not separated from the total mill demand.

6.2 ENERGY SYSTEM

6.2.1 System Capacity

The 425S boilers were each rated at 6532 kg/h (14,400 lb/h) of steam from feedwater at 100 C (212 F), on fuel at 7% MC with a HHV of 19.79 MJ/kg (8500 BTU/lb). In the STOTT application, operating on a wetter fuel and with a lower feedwater temperature, the rated output would have been lower. Information supplied by mill personnel indicated a capacity of 6,078 kg/h of steam at a pressure of 1590 kpa and a temperature of 310 C.

6.2.2 Boiler Input/Output

Based on an assumed combustion efficiency of about 70% when operating on debarker residue fuel with 32% MC and a HHV of 20.36 MJ/kg, the required fuel input for full capacity operation of the two boilers would have been about 2300 dry kg/h. With a fuel ash content estimated at 2.3% (from literature values for the wood and bark of the species being utilized) and excess air assumed to be 70%, a rough input/output mass balance for the boilers would be:

Input (kg/h)			Output (kg/h)		
Fuel:	Wood/Bark	2,247	Steam		12,156
	Ash	53			
	Water	1,082	Stack Gases:	Ash	53
Combustion Air		22,540		Water Vapour	2,313
Feedwater		12,156		Combustion Gases	23,545

In this balance a number of factors have not been included:

- no estimate of boiler blowdown has been attempted, with the feedwater therefore underestimated by that amount. Also, the chemicals added to the feedwater and removed in the blowdown have been ignored.

- there is no provision for regular ash removal from these boilers therefore it is assumed that, except for accumulation of ash in the boiler tubes, the input ash in the wood fuel exits in the stack gases. No attempt has been made to estimate the amount of inorganic contaminants (such as dirt and sand) carried in with the bark. Since the mill did not utilize a log pond, this could have been a significant quantity, particularly in the wet seasons when logs were muddy.

- water vapour in the combustion (and excess) air has not been included in the input or output.

6.2.3 Turbine/Steam System

At full boiler capacity, input to the turbine was about 12,150 kg/h of medium pressure steam. From the turbine performance curve, the net power output at this steam rate would have been about 970 kw. The total connected motor load for the energy system componenets (from nameplate listings) was 170 kw. Of this, 42 kw was for standby units

utilized only in the event of main component failures. Peak load would have been 90 kw (assumed as 70% of nameplate rating), while average load would have been about 85 kw (assumed as 70% for constant duty motors and 50% for intermittant operation motors). Therefore, the net power output from the energy system was about 885 kw.

Of the total low-pressure steam from the turbine exhaust, about 1350 kg/h was used for building heating and about 1500 kg/h was utilized for boiler feedwater heating. The majority, about 9300 kg/h was vented directly to the atmosphere.

6.2.4 Energy Balance

A very rough energy balance for the boiler/turbine complex shows that total potential energy input as boiler fuel would have been about 47 GJ/h (2300 kg/h at 20.4 MJ/kg), while the net outputs would have been about 3 GJ/h to building heating (1350 kg/h of steam at 2.2 MJ/kg), plus about 3.2 GJ/h in the form of electricity (970 kw generator output minus 85 kw internal use in the energy system).

Of the total energy contained in the input fuel, roughly 13% was delivered as usable energy to mill processes. The largest loss segment was the vented exhaust steam which represented over 50% of the input energy or 25 GJ/h (9300 kg/h at 2.7 MJ/kg).

6.3 Fuel-Log System

6.3.1 System Capacity

The stated design capacity for the fuel-log plant was 7000 tonnes per year on a two-shift basis. If it is assumed that two-shifts would give about 15.5 actual operating hours per day, then a 235 day year would require an hourly production rate of 1.92 tonnes with no downtime. The system that was installed consisted of two presses, each rated at 1.0 - 1.25 t/h. Thus, a capacity of 2 t/h on a dry weight basis has been adopted for calculations on mass and energy balances.

Although the press could tolerate feedstock MC's from 7 to 10%, best results had been obtained on a feedstock with 6.5 - 7.5% MC. At an average value of 7%, the actual furnish delivery rate would have been 2.15 t/h, equivalent to 3.23 t/h of raw feedstock from the storage silo.

Dry furnish was also used as fuel for the suspension burner that provided heat for the flash dryer. This burner was rated at 10.5 GJ/h (10 million BTU/h) and fuel consumption was specified as 590 kg/h (1300 lb/h). Based on a furnish MC of 7% and HHV of 19.2 MJ/kg, the fuel requirement for the rated output (assuming 95% burner efficiency) would have been about 620 kg/h. Since the burner was found to be marginal in terms of heat delivery and was run at maximum capacity, the higher fuel rate (equivalent to 577 dry kg/h) has been adopted.

Of the 2577 dry kg/h of feedstock input to the fuel-log plant, about 78% was output as primary product.

6.3.2 Energy Balance Considerations

The energy requirements for the fuel-log operation consisted mainly of thermal energy for furnish drying and electrical energy for the mechanical work. In addition, there were minor requirements such as: fuel-oil for startup of the burner, electricity for the press water heaters and lighting, and diesel fuel for mobile equipment. No data on these individual items was available and they have not been included in the analyses.

The thermal energy required for feedstock drying has been established on the basis of fuel consumption as about 11 GJ/h. On the basis of moisture removal (1385 kg/h), the dryer energy requirement was 7.9 MJ/kg which is approximately double the energy requirement generally associated with a suspension dryer. This low efficiency was apparently related to the lack of insulation on the dryer, a relatively high exhaust temperature and incomplete fuel combustion in the burner.

The total connected electrical (motor) load in the fuel-log plant was listed as 491 kw. If a load factor of 70% is assumed for the steady state operation, then the average load would have been about 344 kw. This is consistent with the observation that the fuel-log plant could be run with the standby diesel generator which was rated at 375 kw.

An approximate energy balance for the major components of the fuel-log system would be:

Input:	Feedstock	2577 kg/h at 19.3 MJ/kg = 49.7 GJ/h
	Electricity	344 kw = 1.2 GJ/h
Output:	Fuel-logs	2000 kg/h at 19.3 MJ/kg = 38.6 GJ/h

Although this balance shows that the theoretical energy content of the product represents about 75% of the energy inputs, this comparison is of no practical value because of the different energy quality of the inputs/outputs. A more appropriate balance could be set up based on net expected energy values. For example:

Input:	Feedstock	2577 kg/h at 19.3 MJ/kg at 67% efficiency = 33.3 GJ/h
Internal Use:		577 kg/h for burner 344 kw at 25% efficiency = 257 kg/h for electricity production
Output:	Fuel-logs	1743 kg/h at 19.3 MJ/kg at 76% efficiency = 25.6 GJ/h

This shows that the net energy loss is about 23% to effect a fuel benefication from wet particulate to dry logs. If the dryer performance were brought to normal industry practice, the fuel requirement would drop to about 300 kg/h, (equivalent to 29.6 GJ/h) and the energy loss would be only 11%.

6.4 Integrated Plant

Although individual plant sectors have been considered on a full production, steady-state basis (i.e. mass or energy flows per hour) these values are not appropriate for considering the entire plant balance because of the different operating conditions in each sector. Further, there are several basis on which a balance can be considered, such as, actual operation achieved, or predicted operating conditions when long-term operation would have been achieved.

For this analysis, a full operating year has been selected as the time basis and three levels of operation are considered: design projections, operation achieved and "optimized" operation.

6.4.1 Design Projections

Specifications for the fuel-log plant and the energy system were prepared by Air Plants (Sales) Limited, Leicester, England. Data used as the basis for the specifications and the estimated mass balance are shown in Table 5. Several factors should be noted:

- no provision was made to utilize wood residues to supply energy for drying of the fuel-log furnish; estimates were based on use of an oil-fired dryer system.
- boilers were to be operated only during mill operation.
- the fuel-log plant was to be operated one full shift, plus a partial second shift based on utilization of the fuel-log furnish available

This data showed a total residue production of 43.1 dry t/d of which 20.9 dry t/d would be required for boiler operation. The remaining 22.2 dry t/d of furnish would supply the fuel-log plant for a full 8 hour shift plus about 5.5 hours of a second shift, sufficient for a yearly output of nearly 4500 tonnes of fuel-logs.

6.4.2 Operation Achieved

Actual operating levels achieved and a resultant fiber balance are shown in Table 6. Major changes from the design projections were:

- a slight reduction in sawmill operating time per day and a significantly lower hourly production rate had been achieved.

- the suspension dryer for the fuel-log furnish was fired by a wood-fuel burner using dry furnish.

- the boilers were operated around the clock in order to maintain building heat and reduce the thermal stress on the boilers from frequent shutdowns.

- a higher capacity fuel-log system was installed.

Actual residues per unit of lumber output were slightly greater than originally predicted but the lower sawmill production rate significantly reduced the daily residue output from a predicted 43.1 t/d to only 38.7 t/d. The greater number of operating days per year however, raised yearly residue production to 9103 t compared to an estimated 8619 t.

Round-the-clock boiler operation increased the fuel requirement by about 4.2 tonnes per operating day and use of wood fuel to fire the suspension burner on the furnish dryer increased the fuel requirement by about 4.6 t/d.

The total fuel requirment of 29.8 t/d (6994 t/y) thus left only 9.0 t/d available as furnish for the fuel-log plant. This is 7.0 t/d (1651 t/y) short of the requirement for full capacity output from a single shift of the fuel-log plant. At the low sawmill production rate achieved, even the total clean wood residue yield was insufficient to sustain the fuel-log plant on a full 2-shift basis.

6.4.3 "Optimized" Operation

Table 7 shows a residue balance for an operating schedule which combines the expected original projections with improved operating performance but within the actual system limitations. Specific changes were:

- sawmill capacity was increased to the original daily target of 59 m3 of lumber output on a 1-shift basis.

- lumber yield was increased from the 34.5% actually measured to a projected 40%.

- fuel-log plant operation was set at 1-shift per day but extended to a 6-day week

- boilers were operated 8 h/d at full capacity for electricity production during sawmill operation, for an additional 8 h/w at an estimated 20% of capacity to cover the fuel-log extra shift, and 24 h/d for building heat and standby the rest of the year except for the summer shutdown.

- dryer and suspension burner performance were improved.

Operating the sawmill at a capacity of 59 m3/d on a 1-shift basis with a lumber yield of 40% would provide 8619 t/y of clean wood residue plus 2834 t/y of debarker residue, a total of 11,453 t/y or 48.7 t per operating day.

If the fuel-log plant were operated on a 2-shift basis at a production rate of 2 t/h, it would require 7285 dry tonnes of furnish per year. This would leave 1334 t/y of furnish, more than adequate to fire the burner for the furnish dryer if dryer performance (and burner operation) were upgraded to standards normally obtainable in wood particle dryers.

However, even with the slight excess of clean wood residues (estimated at 241 t/y) added to the total debarker residue (2834 t/y), the total fuel available would be inadequate for the required boiler operation. In fact, only about half the required fuel would be available, a shortfall of roughly 13 tonnes per operating day.

A more realistic option would be operation of the fuel-log plant on a single-shift basis, but with operation extended to 6 days per week. This would require 4,512 t/y of fuel-log furnish leaving 4,107 t/y for use as fuel. When combined with the available debarker residue a slight excess of 1.7 t/d would result after the boiler fuel and dryer fuel requirements were satisfied.

Table 5 Residue Balance I: Plant Design Projections

Basis:
- 200 d/y operation
- 8 h/d of sawmill operation at a capacity of 59.0 m3/d
- 8 h/d of boiler operation at full capacity and 5.5 h/d of boiler operation at 20% capacity
- 13.5 h/d operation of fuel-log plant at a capacity of 1,649 kg/h

Fiber Balance (dry tonnes per year)

Residues Produced:	Debarker Residue	2,268
	Chips and Sawdust	6,351
	TOTAL	8,619
Residues Required:	Boiler Fuel	4,186
	Fuel-log Furnish	4,452
	TOTAL	8,638
	NET BALANCE	+ 19

Table 6. Residue Balance II: Operation Achieved

Basis:
- 235 d/y operation
- 7.5 h/d of sawmill operation at a capacity of 44.3 m3/d; lumber yield of 34.5%
- 8 h/d of boiler operation at full capacity and 16 h/d of boiler operation at 10% of capacity, plus 107 days for 24 h/d at 10% of capacity
- 8 h/d operation of fuel-log plant at a capacity of 2000 kg/h

Fiber Balance (dry tonnes per year)

Residues Produced:	Debarker Residue	2,129
	Chips and Sawdust	6,974
	TOTAL	9,103
Residues Required:	Boiler Fuel	5,907
	Dryer Fuel	1,087
	Fuel-log Furnish	3,760
	TOTAL	10,754
	NET BALANCE	- 1,651

Table 7. Residue Balance III: Target Capacity, Improved Performance, Altered Schedule

Basis:
- 235 d/y operation of sawmill; 282 d/y operation of fuel-log plant.
- 7.5 h/d sawmill operation at an output capacity of 59 m3/d; lumber yield of 40%
- 8 h/d operation of fuel-log plant at a capacity of 2000 kg/h
- boiler operation: 8 h/d at full capacity for 5d/w; 8 h/d at 20% of capacity for 1 d/w; 16 h/d at 10% of capacity for 6 d/w; plus 61 d/y for 24 h/d at 10% of capacity

Fiber Balance (dry tonnes per year)

Residues Produced:	Debarker Residue	2,834
	Chips and Sawdust	8,619
	TOTAL	11,453
Residues Required:	Boiler Fuel	5,872
	Dryer Fuel	677
	Fuel-log Furnish	4,512
	TOTAL	11,061
	NET BALANCE	+ 392

7.0 OPERATIONAL PROBLEMS

7.1 Technical Problems

During the startup phase and during the relatively short operating period of the integrated plant, a number of technical problems were encountered. These not only placed severe limitations on system performance, but often caused plant shutdowns as a result of component failures. Several major problem areas are discussed, including speculation on causal factors and the possible solutions that were being considered.

7.1.1 Suspension Burner

The cyclonic burner which supplied hot combustion gases to the fuel-log furnish dryer did not operate satisfactorily. The heat output from the burner was barely adequate for the required dryer load which necessitated operation of the burner at maximum output. Under these conditions, the burner residence time was insufficient and particles of burning fuel were carried into the dryer, causing fires in the dryer and even in the dry fuel storage bin. There appear to have been several factors which contributed to the poor burner design. The flash dryer, which extended through the building roof, was not insulated and the heat requirement of the dryer was substantially greater than that normally associated with wood particle dryers. Also, the burner fuel was fuel-log furnish which had been prepared to -13 mm, much coarser than the -3 mm often associated with suspension burners.

Modifications were made to the system with a burnout chamber added and a set of screens placed at the inlet to the dryer fan. This approach proved unsatisfactory as unburned particles plugged the screens which restricted flow through the furnace, causing overheating and failure of the refractory in the furnace.

Contemplated remedial measures included: reduced thermal load through dryer insulation, a larger capacity burner with increased residence time, and a screen system to remove fines from the fuel-log furnish for use as burner fuel.

7.1.2 Generator Capacity

The maximum operating capacity of the twin boilers and turbine-generator was barely sufficient to cover the total plant electrical load. As a result there was insufficient power to handle electrical demand surges, such as when a large cant entered the gang saw.

The installation of a capacitor system for load regulation had been examined and consideration given to operating the sawmill and fuel-log plants on staggered shifts. Provision had been made in the boiler room and turbine room for the later addition of a third boiler and second turbine.

7.1.3 Log Debarker

The rosser head debarker installed in the mill proved too slow and not sufficiently robust for the job of handling the hardwood logs available to the project. This resulted in excessive downtime to repair debarker breakdowns and loss of mill capacity as the sawyers waited for logs to be debarked.

Consideration had been given to either a larger, heavy-duty debarker, or to a second debarker and infeed system to supply short or small logs directly to the Scrag saw.

7.1.4 Residue Handling Systems

Difficulties were experienced in several areas of the residue handling, storage and retrieval system. These included: sawdust plugging (particularly at the gang saw), bridges in the silos and fuel metering bin, and plugging of the outside hogged bark transfer pipe when the ambient temperature was around freezing and the humidity was very high.

Corrective actions would have included improved bin and silo designs and the use of belt conveyors instead of pneumatic systems.

7.1.5 Boiler Operation

Several problems were encountered in the initial period of boiler operation. During startup, the superheater tubes overheated as a result of the low steam flow. This was corrected by installing a water circulation system to cool the tubes until adequate steam flow had been established.

A buildup of a glassy slag was experienced on the refractory walls of the combustion chamber. The refractory was removed from the top half of the combustion chamber, which improved heat transfer and eliminated the slagging.

Early attempts were made to run the boilers only for 8 hour periods each day. The thermal changes caused by this repeated startup-shutdown cycle caused leakage where the fire-tubes were rolled into the tube-sheet. This problem was avoided by maintaining the boilers on low-fire operation during all off-peak hours.

7.2 Non-Technical Problems

In addition to technical problems in mill operation, the STOTT project encountered major non-technical setbacks associated with such diverse aspects as financing, marketing, and administrative/infrastructural.

7.2.1 Financial

At the time of peak project debt the interest rates jumped from a budgeted 9% to the exorbitant level of 24%. This produced excessive carrying costs for the debt load at a time when full market potential had not yet been realized. This was a major factor in the financial collapse of the enterprise.

Little potential for corrective action existed since the interest rates were a reflection of the recession being experienced in most of the forest industries.

7.2.2 Marketing

The major mill product was mine timbers, with 80% of production contracted to a single customer (who had existing sources of supply and was disinclined to provide encouragement to the local project). This led to conflicts over product suitability, lower prices, increased production costs and late payments.

An improved situation would have required a more diversified customer base, more precise contract specifications, and better coordination and communication between government and industry, and within government departments.

7.2.3 Raw Material

Sawlogs were being obtained from crown land which was under lease to a major pulp company. Although they had no use for the hardwood, this company was generally opposed to harvesting operations by a small private organization. In addition, the volume of suitable material was often well below the predicted stand inventories. These problems had contributed to high harvesting (raw material) costs.

Avoidance of this type of problem would have required better integration of resource data with the projected mill design and harvesting system. Greater responsibility by resource officials (less political influence) would also have contributed to a more positive situation.

7.2.4 Government Programs

There is evidence that pressure from government agencies required the project to conform to existing financial support programs, resulting in technical compromises. This resulted in time delays, extra expenses and the installation of economically inappropriate systems. An improved situation would have resulted from better inter-government communications, priority to technical rather than bureaucratic approvals, and lessened political control over programs.

8.0 CONCLUSION

Without sound technical data gathered over an extended period of routine operation and without a detailed, comprehensive economic analysis of the operation, it is difficult to make statements that can realistically be defined as conclusions. However, it does appear valid to conclude that this project confirms a number of generally accepted guidelines regarding the establishment and operation of a forest products complex.

8.1 Sawmill

The importance of careful integration of actual resource quality with the mill design was confirmed. Lower than anticipated stand volumes and higher cull than expected contributed to high raw material costs, reduced mill capacity, low primary product recovery and increased equipment failures.

That experienced key personnel are crucial to efficient mill startup was illustrated. Mill management concluded that an expert head sawyer and maintenance foreman with extensive background experience in the specific type of operation being established were essential. They should be hired on a contract basis (for a minimum of one year term), to ensure continuity during the startup and training period.

8.2 Energy System

Startup difficulties with the boiler-turbine system confirmed that for superheated steam operation it is essential that the services of a fully qualified, experienced chief stationary engineer be contracted.

The commercial availability of a straightforward, reasonable cost, small-scale steam-cycle electrical generating system for operation on wet wood residues was confirmed. The system major components were technically sound, easy to operate and performed well for steady-state base loading. However, it was also clearly established that the system was not suited to intermittent operation on a single-shift basis. To avoid boiler failure, the system must be kept hot, which requires full-time staffing. This experience confirms the accepted axiom that steam-cycle generation of electricity is practical only on a round-the-clock operating basis.

Although an economic analysis was not attempted, it was obvious that the poor economics of small-scale electricity-only generation were being demonstrated. The value of the electricity being displaced (from the grid) was probably little greater than the operating costs of the energy system. This indicates that a substantial subsidy was required to justify generation of electricity. A general comparison between the energy system and the fuel-log system (similar capital

cost, comparable staffing and probably lower operating costs), suggests that an electricity value in the order of $0.30 per kwh would be required to provide the same return from a tonne of residue.

The poor thermal efficiency of electricity generation was also illustrated. Less than 7% of the residue fuel energy was output as net electricity, while only about 13% of the input energy in the fuel was actually being utilized. This data supports the concept that generation of electricity should be considered only as a topping cycle after the requirement for full utilization of the exhaust steam has been established. In the STOTT mill, kiln-drying of the full board production would require only a fraction of the exhaust steam available. An approximate balance would be obtained only if the sawmill were operated on a 3-shift basis and all timber produced was kiln-dried.

8.3 Fuel-log System

The technical (and probably economic) feasibility of producing a binderless compressed wood fuel-log from hardwood mill residues was confirmed. Although not competitive as a base fuel in N. America, the product showed good potential as a replacement for solid-wood fireplace logs in urban applications and as a household fuel for export to Europe.

8.4 General

In all three sectors of the mill, the difficulty in handling wood residues was demonstrated. Problems were encountered in storage silos, pneumatic transport lines, screw conveyors and metering bins.

9.0 SUMMARY

The STOTT Timber Co. plant in Cape Breton had not achieved full-capacity, steady-state operation of the integrated complex (hardwood sawmill; fuel-log plant; electrical generating system) when forced to close as a result of financial difficulties. The full objectives of the ENFOR project, therefore, could not be realized as the majority of the technical data were to be collected over a one-year operating period after routine normal operation of all systems had been achieved.

Although a victim of adverse economic times, compounded by significant infrastructural problems and some technical difficulties, the project did have a number of positive aspects including:

- The mill was established to utilize a renewable resource which, at the time, had no other viable market. The mature and over-mature hardwood stands on pulp company limits were often a silvicultural hindrance to the growth of the preferred softwood species.

- The major product, mine timbers, was dedicated to a local demand previously being supplied by the importation of out-of-province material. The demand for this product had been projected to double in the near-term.

- Mill operation contributed directly to an improved regional economy through the creation of more than 45 jobs.

- The project had a substantial positive energy contribution through the marketing of a wood based fuel (potentially able to displace petroleum or coal) while generating the required mill electrical and thermal requirements internally.

- The systems selected were, overall, technically proven concepts that could meet the operating objectives of the mill complex.

The brief operation of the STOTT plant demonstrated that energy self-sufficiency and total residue utilization are not technically limited. Small-scale commercial systems are available that, when properly designed, installed and operated, will meet performance specifications and provide marketable products. The constraints on implementation are largely economic with financial viability dictated by utilization factors.

Operation of a steam-cycle system for generation of electricity on a single-shift basis was shown to be impractical, technically unsound, and not economically viable. Greatest potential would exist in an application where 3-shift operation was possible with total lumber output kiln-dried using the exhaust steam and clean residues not required as fuel coverted to fuel-logs in a 3-line press system.

10.0 APPENDICES

10.1 Appendix I. Enfor Project Statement of Work

SCHEDULE A

Technical and economic assessment of energy self-sufficiency in a small hardwood sawmill through total residue utilization by conversion to thermal and electrical energy plus a marketable densified biomass fuel.

Statement of the Problem

Forest products industries in eastern Canada are presently experiencing difficulties in maintaining a competitive market position due to rapidly escalating energy costs, often compounded by high costs for environmentally acceptable disposal of their substantial mill residues. As a result most firms are actively investigating systems for the conversion of mill residues into useful energy, either thermal or electrical. Technically and economically proven equipment is available for generating process heat by direct residue combustion but this consumes only a very small portion of the residues. Also, it offers no solution to the ever increasing electrical bills which are particularly acute in the eastern provinces where hydro is scarce and much of the electricity is produced by burning imported oil.

Generation of electricity from mill residues has been considered economically viable only in very large installations such as pulp mills where economies of scale and high electrical and thermal load factors enable efficient high pressure boiler - steam turbine-generator systems to produce electricity at costs competetive to the utilities. Recently however, considerable interest has been shown in small scale steam cycle systems, particularly those of European design, which offer considerable potential when combined in a total energy system to supply a large thermal requirement as well as the electrical load. Unfortunately none of these systems is presently operating in eastern Canada and reliable information on performance, operating characteristics and costs are difficult to obtain.

A similar situation exists with regard to the newer systems for producing densified residue-based fuels, a possible solution for disposal of the residues remaining after total mill energy requirements are satisfied. Several systems are operating on a relatively large scale in the Western U.S. but information on operating characteristics and costs are not available for the small scale situation of the eastern Canadian mill.

Objectives

- to demonstrate the total utilization of residues from a small sawmill for the production of energy by on-site combustion to generate total mill electrical and thermal requirements plus conversion of remaining residues to a marketable, energy-dense biomass fuel.
- to acquire specific, detailed, technical information on the fibre and energy balances of all aspects of an integrated sawmill - fuel log plant.
- to obtain complete costing and operating data on the construction, startup, testing and operation of a small scale steam-cycle electrical generating system.
- to obtain technical and economic evaluation of the production and marketing of a residue-based, densified fuel.
- to create a model of small scale residue-energy systems for use in sensitivity analyses and as the basis for feasibility studies of similar mill systems in eastern Canada.

Work to Be Done

It is understood that the contractor is constructing in eastern Canada an integrated plant to convert local hardwood logs into mine timbers, lumber and residue based fuel logs. This involves a conventional sawmill for primary conversion, a fuelog system for conversion of dried, logged wood residues into a densified fuel for industrial or household use, and an energy system comprising residue fired boilers to supply medium pressure steam to a back pressure turbine - alternator set to generate total mill electrical requirements plus provision for mill heating and the principal energy required for drying of the fuel log feedstock.

The contractor will engage a suitably qualified individual on a full time basis for a period of approximately 12 months to obtain, compile, evaluate and assess data on the installation and operation of the integrated plant and prepare a report for presentation. Specifically this will involve at least:

A For the sawmill operation

1) Prepare a detailed fibre audit
   - establish log input, lumber output, residue production
   - provide data on conversion factors, moisture contents, bulk densities, etc.

2) Prepare a detailed energy audit

- for each piece of equipment provide data on electrical peak loads with frequency and duration, average loads for work and idle, power factors, motor ratings and performance, etc.
- provide data on thermal requirements of the mill and on thermal contributions from lighting, machinery, etc.

B For the fuel log operation

1) Determination of feedstock characteristics and assessment of the effect of feedstock variation on quality of prepared fuel.
   - particle size and size distribution; type of pulverization
   - moisture content and uniformity
   - composition, eg. proportion of bark, sawdust, shavings, chips; softwood - hardwood ratio; inclusion of foliage etc.
   - quality, eg. type and duration of feedstock storage, content of inorganics and contaminants etc.
   - binders or additives for moisture resistance or amendment of burning characteristics.
   - temperature of feedstock

2) Evaluation of energy balance
   - thermal and electrical inputs required for each aspect of the system eg. feedstock preparation, extrusion, handling and shipping etc. expressed per unit output and per unit of energy content
   - load factors for thermal and electrical energy with time - demand curves
   - relationship of energy balance to feedstock and prepared fuel quality

3) Evaluation of the prepared fuel
   - specific characteristics; S.G., bulk density, heating value, energy density, ash content, etc.
   - environmental implications such as dust hazard, particulate emission potential etc.
   - effect of handling and shipping on the production of fines
   - effect of exposure to weather on fuel stability
   - burning characteristics as related to fuel size and composition
   - relationship of fuel quality to processing variables such as pressures, temperatures developed in extruder, etc.

4) Economic implications
   - manpower requirements, skills, training etc. required for each aspect of production
   - operation and maintenance requirements, downtime, production rates, die wear rates etc.
   - prediction of minimum and optimum plant sizes and operating variables
   - prediction of maximum feedstock value to allow economic processing for industrial fuel or household fuel
   - calculation of economic feedstock supply distances and product shipping distances
   - assessment and interpretation of marketing strategies.

C For the residue-energy system

1) Prepare a detailed analysis of boiler operation

- determine combustion efficiency and variation with fuel characteristics and moisture content
- evaluate particulate and gaseous emissions
- provide data on electrical energy consumption in the preparation of boiler fuel and boiler auxilliaries
- monitor feedwater and provide data on chemical treatments required
- evaluate quantites of ash, frequency of removal and provide information on ash disposal
- provide data on manpower requirements, operation and maintenance costs etc.
- evaluate boiler performance in terms of response, adequacy of control etc.
- provide a heat balance for boilers including various sources of heat losses

2) Provide data on turbine and generator efficiencies under full and partial loads, frequency variation, blade and seal erosion etc.

D For the total integrated complex

For all equipment, monitor performance and provide records of operating time, downtime, non-productive operation, repairs and maintenance required etc. and provide comments and recommendations on all problems, solutions to problems adequacy of equipment etc.

It is understood that the contractor will provide reasonable access to all data, costs etc. during the contract period and permit reasonable modification to operating procedures and parameters for test purposes to generate technical data of mutual interest.

Results Expected

It is expected that the contractor will provide monthly progress reports and provide all basic data generated.

A final report is required to provide a concise assessment of the installation, startups and operation of an integrated residue-energy system, fuel log preparation plant, and sawmill; and to provide an optimized design (model) for a small energy-self-sufficient hardwood sawlog conversion plant employing total residue utilization.

10.2 Appendix II. Fuel Log Test Results

Forintek Canada Corp.
800 chemin Montréal Road, Ottawa, Ontario K1G 3Z5 Téléphone (613) 744-0963 Télex 053-3606
Eastern Laboratory
Laboratoire de l'Est

38-80-599

November 18, 1985

Mr. D. Huffman
ENSYN Engineering Associates Inc.
275 MacLaren Street
Ottawa, Ontario
K2P 9L9

Dear Don:

Enclosed are the results of the analysis performed on the fire log you supplied to us. Higher heating value, ash content, specific gravity and water stability were determined.

A sample of wood taken from the centre of the fire log was ground to 40 mesh. Bomb Calorimetry was performed on the sample and then later corrected for moisture to obtain the higher heating value. Ash content was determined on oven dry material.

Specific gravity values were determined according to ASTM Standard test method -D2395. The values are recorded on an oven dry basis. A visual test was performed for water stability.

I trust this is to your satisfaction, if there are any questions please feel free to contact us. An invoice for our services is enclosed.

Yours Sincerely,

FORINTEK CANADA CORP.

B.S. Lethbridge

B.S. Lethbridge
Technician
Dept. Composite Wood Products

	1	2	3	Average
Higher Heating Value				
cal/g	4603	4622	4619	4615 cal/g
btu/lb	8285	8320	8314	8306 btu/lb
% Ash Content	0.48	0.45	0.48	0.47 %
Specific Gravity g/cm^3	1.107	1.101	1.098	1.102 g/cm^3

Water Stability

- within 1 minute of submersion, particles started to breaking away from the sample
- within 1.5 minutes the sample had swollen to double its size
- at 3 minutes the sample disintegrated

(We conclude poor water resistance)

10.3 Appendix III. Reference Data

Table 1. Wood Moisture Content (percent wet basis)

Yellow Birch:	heartwood	42.5	(Reference 1)
	sapwood	41.9	(" ")
White Birch:	heartwood	47.1	(" ")
	sapwood	41.9	(" ")
Hard Maple:	heartwood	39.4	(" ")
	sapwood	41.9	(" ")
Soft Maple:	heartwood	36.7	(" ")
	sapwood	49.2	(" ")
Hard Maple Bark:		28.7	(Reference 2)
		36.8	(" ")

Table 2. Wood Specific Gravity

Yellow Birch:	0.55	(Reference 1)
	0.559	(Reference 3)
White Birch:	0.48	(Reference 1)
	0.506	(Reference 3)
Hard Maple:	0.56	(Reference 1)
	0.598	(Reference 2)
	0.597	(Reference 2)
	0.597	(Reference 3)
Soft Maple:	0.49	(Reference 1)
	0.516	(Reference 3)
Yellow Birch Bark:	0.576	(Reference 4)
Hard Maple Bark:	0.583	(Reference 4)
	0.662	(Reference 2)
	0.644	(Reference 2)

Table 3. Wood and Bark Higher Heating Values (MJ/kg)*

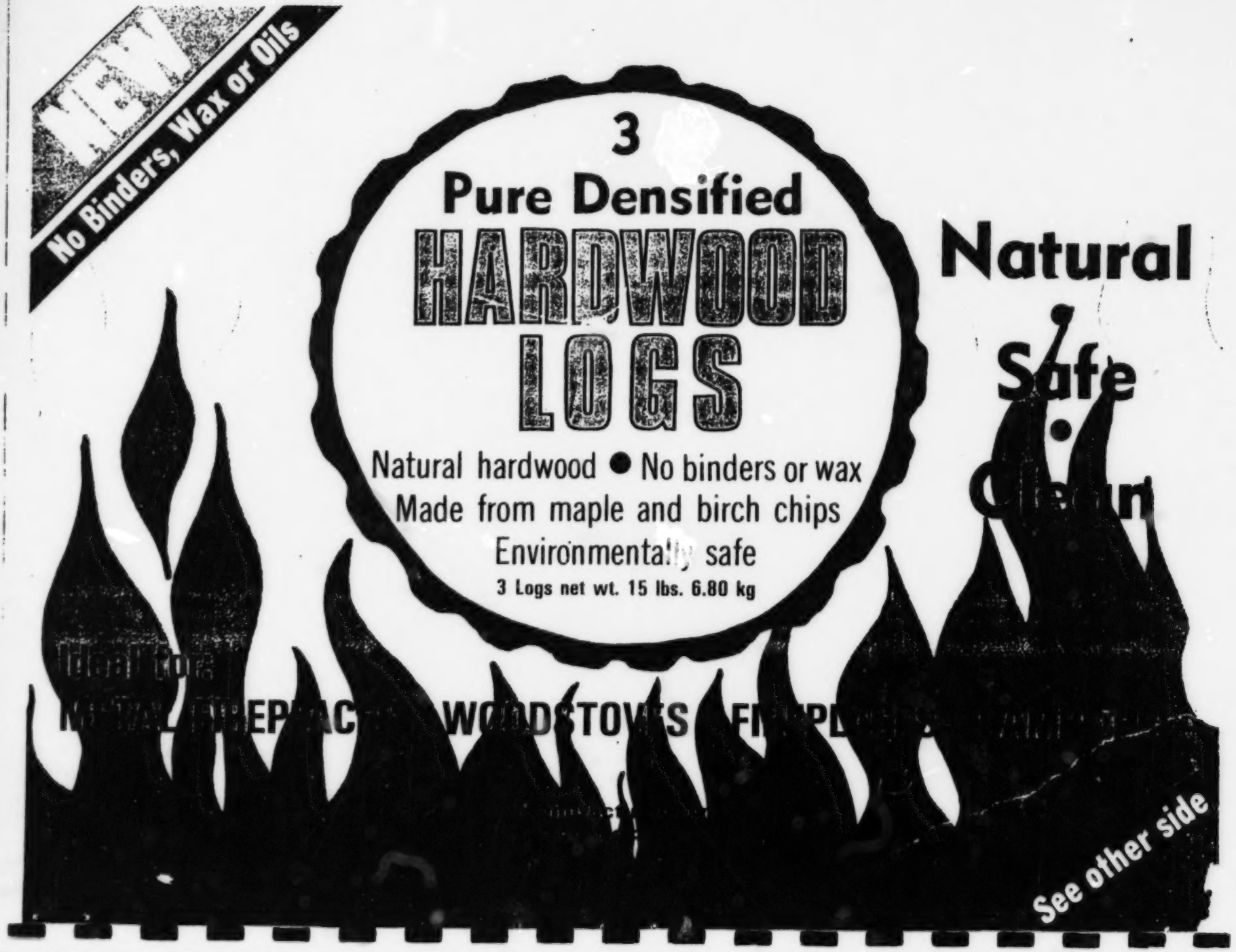
	Wood	Bark
Yellow Birch:	19.8	21.8
White Birch:	19.8	23.7
Hard Maple:	19.7	18.8
Soft Maple:	19.6	18.5

* Average values from Reference 5 after adjustment for ash and moisture content variations.

Table 4. Wood and Bark Ash Contents (% dry weight)

Wood:		
Yellow Birch	2.7	(Reference 8)
White Birch	0.29	(Reference 7)
Birch	0.29	(Reference 6)
Hard Maple	0.9	(Reference 8)
Maple	1.35	(Reference 7)
Maple	1.3	(Reference 9)
Bark:		
Yellow Birch	2.3	(Reference 4)
White Birch	1.8	(" ")
Hard Maple	4.1	(" ")
Soft Maple	3.0	(" ")

10.4 Appendix IV. Fuel Log Package Insert


No Binders, Wax or Oils
3
Pure Densified
HARDWOOD
LOGS
Natural hardwood ● No binders or wax
Made from maple and birch chips
Environmentally safe
3 Logs net wt. 15 lbs. 6.80 kg
Natural
Safe
●
Clean
See other side

10.5 Appendix V. References

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2. Availability and Fuel Characteristics of Eastern Canadian Sawmill Residues. Proceedings of Energy Seminar, Timmins, 1979. Eastern Forest Products Laboratory, Fisheries and Environment Canada.

3. Resistance et Proprietes Connexes des Bois Indigenes au Canada. A.P. Jessome. Laboratoire des Produits Forestiers de l'Est. Rapport Technique de Foresterie 21, Ottawa, 1977.

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5. Determination of Available Heat of Combustion Data for Canadian Woody Species, J.M. Kryla, 1984. Enfor Report P-256.

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